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Advanced Antennas for SAR Spacecraft

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Abstract

Single and multi-frequency antenna concepts have been developed to evaluate the feasibility of building large aperture polarimetric SAR systems to be launched in low cost launch vehicles such as the Delta II. The antennas are 18.9 m long by 2.6 m wide (L-band) and achieve single polarization imaging to an incidence angle of 55° and dual/quad imaging to 42°. When combined with strawman spacecraft designs, both concepts meet the mass and volume constraints imposed by a Delta II launch.

Introduction

Advanced spaceborne SAR missions generally require large aperture antennas to meet the needs of the user community. SAR antenna concepts presented to date, however, have not fully realized the potential of available antenna technologies. The two EOS SAR industry briefing studies, for example, indicated that the largest L/C/X SAR that could be launched in a Delta II has an antenna aperture of only 2.6x10.9 m. The performance of this antenna, particularly with regard to maximum incidence angle ranges, is considerably less than that desired by the science community.

To evaluate the limiting performance of a mass, volume, and cost constrained SAR, an antenna feasibility study was performed. Four constraints were placed on this study:

1) Satisfy known science requirements so as to place the user community ahead of the technology
2) Base the design on the proven SIR-C heritage, minimizing design changes but incorporating new technologies where most useful
3) Design to a Delta 7920 launch to limit launch cost
4) Generate a design which minimizes the number of parts and processes to reduce cost

Alternate design approaches were then examined, based on these constraints, to identify feasible (not necessarily optimal) designs.

Requirements

The science requirements specified by the user community for EOS SAR were used to drive the design. Mission/system requirements were derived from the science requirements. An orbit at 700 km was selected to minimize atomic oxygen exposure and drag and thus extend the spacecraft lifetime. Requirements imposed by selection of the Delta 7920 as a launch vehicle are strong drivers for the spacecraft and antenna designs. While other launch options could be more effective, designing to the Delta option effectively identifies the key technology and cost drivers for the antenna. Both single and multiple frequency design options were considered.

L-band Advanced SAR (LASAR)

The single frequency quad-polarization L-band Advanced SAR (LASAR) concept developed during this study is shown in Figure 1. Characteristics of this antenna are summarized in Table 1. The LASAR antenna is 18.9 m long and consists of seven leaves that fold for launch. Bus and payload subsystems are contained on the backside of the square vertical structure in this figure.

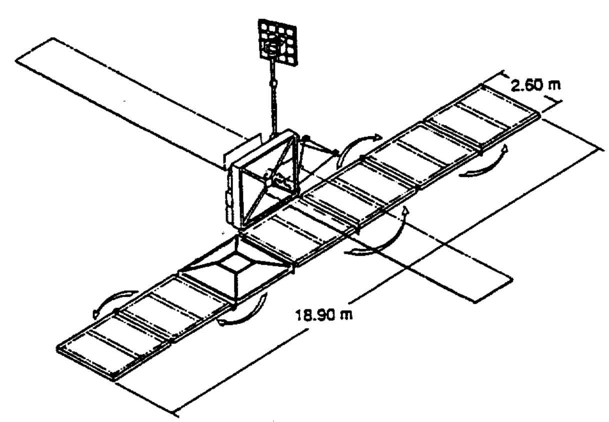

Figure 1 Conceptual illustration of the LASAR spacecraft showing the deployed 18.9 m antenna.

Table 1 Characteristics of the LASAR antenna.

CHARACTERISTIC	VALUE
Array size (m)	18.9 x 2.6
Antenna mass (kg)	511
Peak radiated power (W)	4900
Number of T/R modules	224
Peak output power per T/R circuit (W)	11
Number of leaves	7
Leaf size (m)	2.68 x 2.6
Leaf thickness (cm)	6.4
Panels per leaf	2
Polarization	quad
Elements per stick	6
Sticks per panel	16

The aperture uses the same six-element-per-stick microstrip patch architecture used on SIR-C. as illustrated in Figure 2. This approach maximizes SIR-C heritage in manufacturability as well as performance. The peak radiated power of 4900 W requires a module peak power of only 28 W, well within the capability of current devices. Because the antenna support structure is integral to the panels, total panel thickness is only 6.4 cm.

The use of thin panels allows the 18.9 meter antenna to be folded and stowed within the tight launch shroud of the Delta, as shown in Figure 3 Panels are connected by simple hinges and deployed with reliable motorized actuators. Figure 4 illustrates the first step of this deployment sequence.

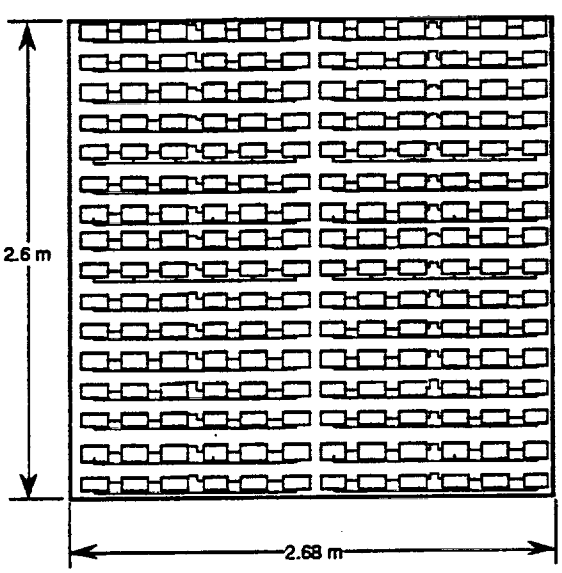

Figure 2 Layout of a leaf showing the microstrip patch elements.

The pattern characteristics of the LASAR antenna are very similar to those of the SIR-C antenna, the most obvious difference being that the azimuth beamwidth is considerably smaller. Figure 5 shows the H-polarization transmit pattern when the beam is scanned 15^{o} off boresight.

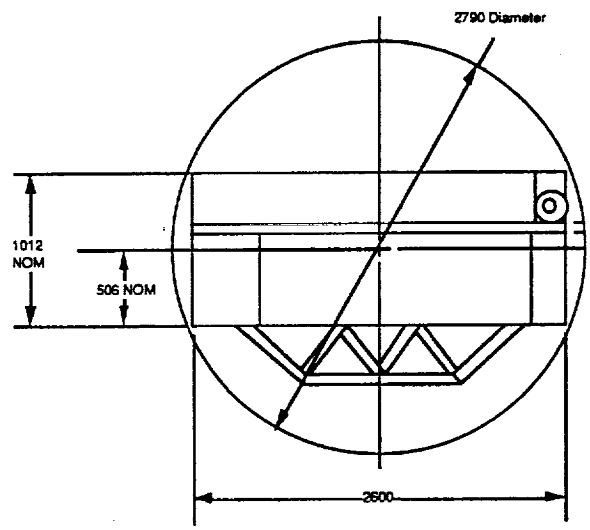

Figure 3 Stowed configuration of the LASAR spacecraft within a Delta 7920 shroud.

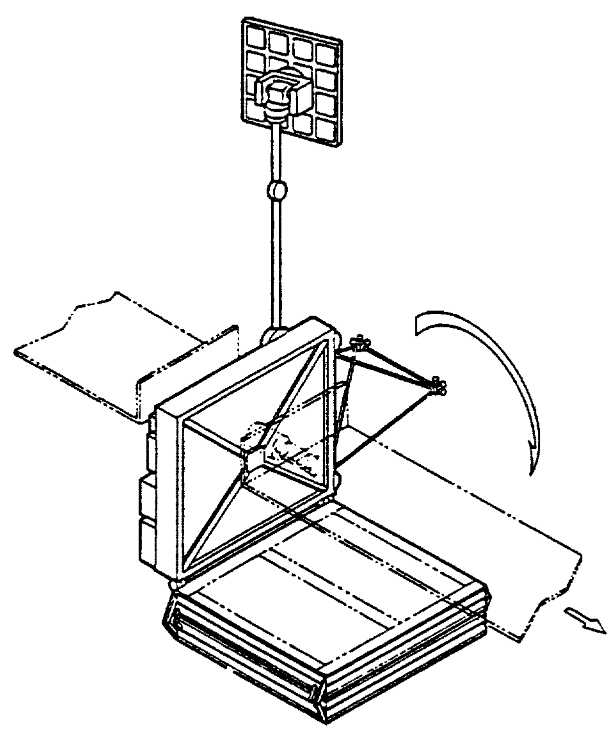

Figure 4 Initial deployment sequence for the LASAR antenna.

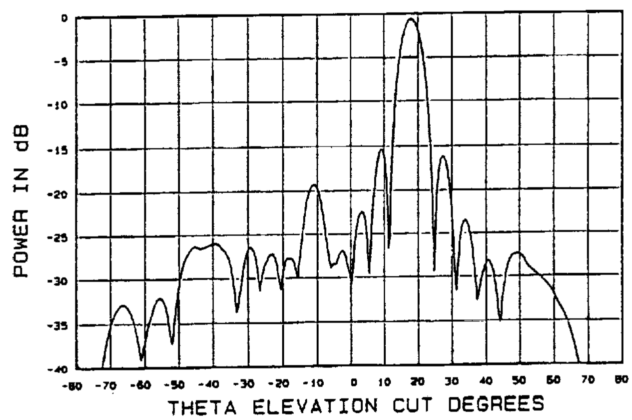

Figure 5 Sample antenna pattern for the LASAR antenna showing the H-polarization transmit beam scanned at 15^o.

Antenna flatness is maintained through the structural integrity of the panels, which are designed with sufficient stiffness to withstand the launch load using materials carefully selected to minimize bending when the antenna is subject to thermal gradients. A thermo-mechanical analysis showed that the antenna maintains the required $\lambda/20$ flatness with a 20% margin.

SAR performance of the LASAR design meets or exceeds all of the known science requirements for EOS SAR. Figure 6 demonstrates both incidence angle and sensitivity performance. The 18.9 m aperture supports imaging to incidence angles of 55^o for single polarization and 42^o for dual/quad polarization. This satisfies the EOS SAR science requirements of 50^o and 40^o respectively and is well beyond the $40^o/30^o$ performance of the 10.9 m aperture presented in the EOS SAR industry briefing. Thermal noise equivalent σ^o of this antenna is -41 dB at 45^o. The maximum SCANSAR swath is 670 km for single polarization and 400 km for dual polarization.

Using mass estimates developed during this study and the EOS SAR industry studies, a mass budget was derived for the LASAR design. This budget is shown in Table 2. Mass savings are obtained primarily from the antenna mass reduction and use of a single-frequency instrument. Additional mass reductions from the industry study values, particularly in the instrument, are expected with further analysis. The LASAR approach meets the Delta launch requirement with considerable margin including design contingency.

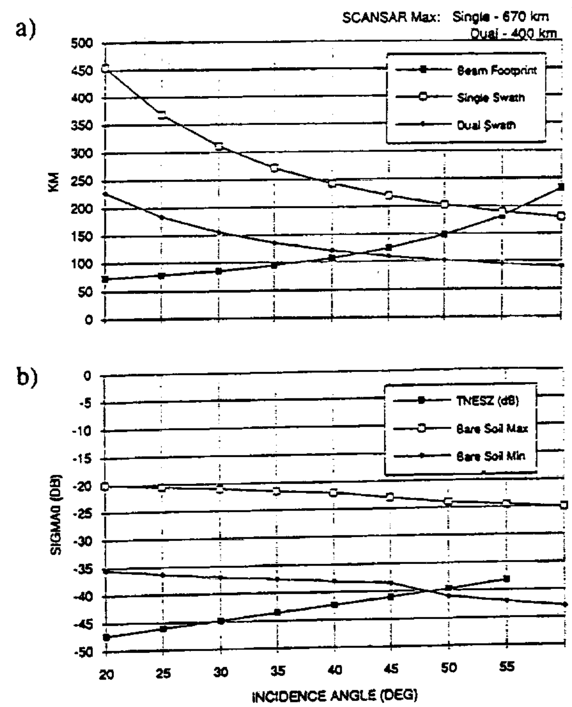

Figure 6 LASAR performance versus incidence angle: a) ambiguity and beamwidth limited swath for single and dual/quad modes. b) thermal noise equivalent σ^o.

Table 2 Mass budget for the LASAR spacecraft.

ITEM	MASS (kg)
Antenna	**511.39**
Flight Electronics	**263.00**
RF electronics	50.00
DDHA	60.00
CTTA	75.00
PCDA	20.00
DDRE	20.00
Harness	30.00
Adapter plate	8.00
Bus System (dry)	**1268.00**
Structure	298.00
AACS	102.00
Cabling	15.00
Propulsion	62.00
Thermal control	30.00
Power	358.00
Command and data	152.00
Mechanisms	148.00
Communications	103.00
Miscellaneous	**698.48**
Launch adapter/misc	100.00
Propellant	90.00
Project reserve	100.00
Contingency	408.48
TOTAL (kg)	**2740.87**
MARGIN (kg)	559.13

Multiband Advanced SAR (MASAR)

The performance advantages obtained through the LASAR design were extended to a multi-frequency system in the MASAR design. The design employs the same general seven-leaf configuration used shown in Figure 1 to obtain an 18.9 meter L/C/X aperture. The characteristics of the MASAR antenna are summarized in Table 3. Peak transmitted power levels were selected to satisfy the science requirements while maintaining a feasible spacecraft DC power budget. Module peak powers are 11 W at L-band, 4 W at C-band, and 4 W at X-band. Panel thickness is the same as for LASAR, providing for the same stowage and deployment procedures.

Table 3 Characteristics of the MASAR antenna.

CHARACTERISTIC	VALUE		
Array size (m)	18.9 x 2.6		
Antenna mass (kg)	711		
Number of leaves	7		
Leaf size (m)	2.68 x 2.6		
Leaf thickness (cm)	6.4		
Panels per leaf	2		
	L	C	X
Polarization	quad	quad	dual
Peak radiated power (W)	1900	1400	1200
Number of T/R modules	224	224	224
Peak power per T/R circuit (W)	11	4	4
Sticks per panel	32	64	64

To obtain the largest possible aperture size for each frequency within the 18.9 x 2.6 m area constraint, a shared aperture approach was used. As shown in Figure 7, the L-band array uses the full area to achieve an aperture size that is the same as that for LASAR. The C-band and X-band apertures *share* the space occupied by the L-band aperture. This approach is known to be feasible at the element level; further work is in progress to understand the impact on performance at the array level.

Antenna flatness is maintained through 1) the structural integrity of the panels, which are designed to be individually flat to the required X-band l/20 flatness, and 2) use of active hinges between panels. A thermo-mechanical analysis showed that, with the inclusion of active hinges, the antenna maintains the X-band $\lambda/20$ flatness across the entire array.

Table 4 provides a mass budget for the MASAR concept, showing that a MASAR spacecraft meets the Delta launch mass requirement, although with only a small margin.

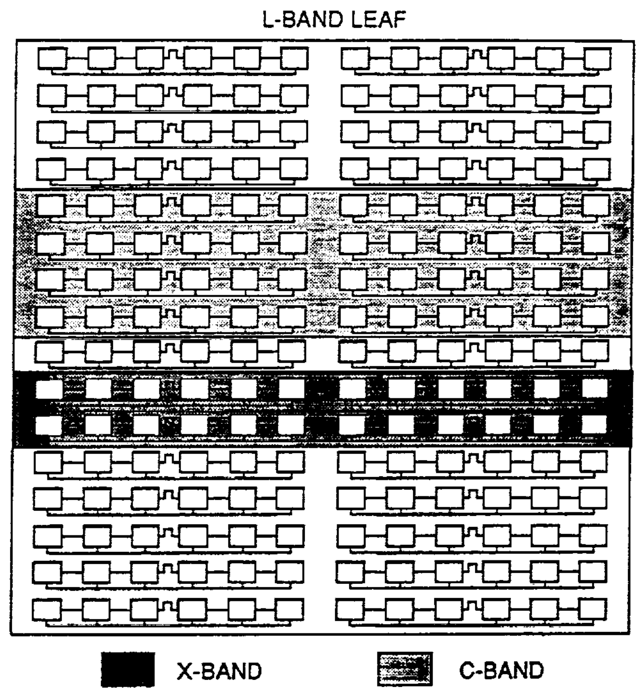

Figure 7 Layout of a shared aperture leaf showing L-band elements and regions of C- and X-band elements.

Table 4 Mass budget for the MASAR spacecraft.

ITEM	MASS (kg)
Antenna	**711.08**
Flight Electronics	**383.00**
RF electronics	91.00
DDHA	75.00
CTTA	114.00
PCDA	27.00
DDRE	23.00
Harness	45.00
Adapter plate	8.00
Bus System (dry)	**1314.00**
Structure	298.00
AACS	102.00
Cabling	15.00
Propulsion	62.00
Thermal control	30.00
Power	404.00
Command and data	152.00
Mechanisms	148.00
Communications	103.00
Miscellaneous	**771.62**
Launch adapter/misc	100.00
Propellant	90.00
Project reserve	100.00
Contingency	481.62
TOTAL (kg)	**3179.70**
MARGIN (kg)	120.30

The importance of the shared aperture approach is shown in Figure 8, which illustrates the incidence angle performance of comparable shared and separate aperture antennas. Both antennas are assumed to have a fixed 18.6 x 2.6 m area available for the aperture. In the shared aperture approach, the L-band aperture uses the full 2.6 m width. In the separate aperture approach, the 2.6 m width is apportioned between the L, C, and X-band apertures so that the L-band aperture has a width of only 1.9 m. As a result, the maximum incidence angle decreases from 55° to 47° for single polarization and from 42° to 33° for dual/quad polarization.

Conclusion

The LASAR/MASAR feasibility study shows that SAR antennas large enough to satisfy the needs of the science user community can indeed be built using non-exotic SIR-C heritage technology and launched with the low-cost launch vehicles.

Acknowledgment

The work described in this paper was performed by the staff of Ball Communication Systems Division.

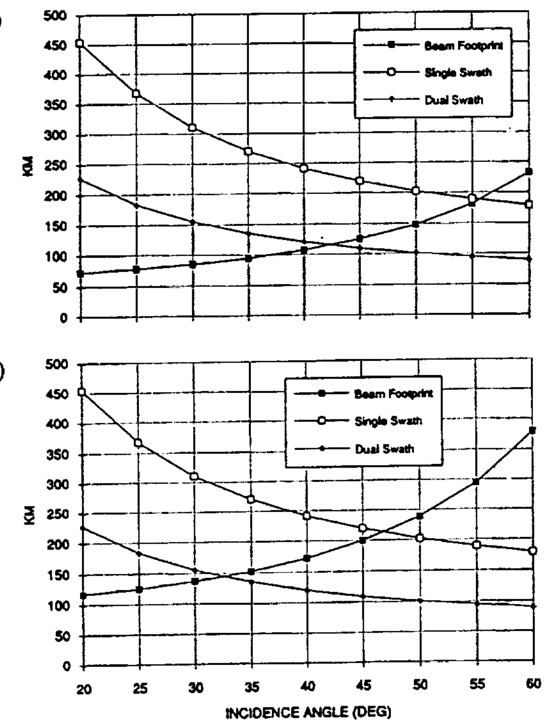

Figure 8 Comparison of ambiguity and beamwidth limited swath versus incidence angle for a) shared aperture, and b) non-shared aperture.

Table 4 Science requirements and compliance of the MASAR spacecraft.

REQUIREMENT	VALUE	DESIGN VALUE
Frequency	L, (C, X)	L, (C, X)
Polarization	quad, (quad, dual)	quad, (quad, dual)
Resolution		
- Local mode	20-30 m	30 m (3 looks)
- Regional mode	50-100 m	50-100 m
- Global mode	250 m	250 m
Incidence angle range		
- Single polarization	15-50 deg	TBD-55 deg
- Quad polarization	15-40 deg	TBD-42 deg
Thermal noise equiv σ^0 @ 45°	-36 dB, (-27 dB, -22 dB)	-37 dB, (-28 dB, -23 dB)
Max single swath width		
- Single polarization	30-50 km	within ambiguity limits
- Quad polarization	30-50 km	within ambiguity limits
Max SCANSAR swath	600 km	>600 km
Calibration		
- Relative amplitude	+/- 1.0 dB	+/- 1.0 dB
- Absolute amplitude	+/- 1.0 dB	+/- 1.0 dB
- Relatvie phase	TBD	TBD
- Geometric	+/- 0.5 pixel	+/- 0.5 pixel
Ambiguity level	<-20 dB	<-23 dB
Sidelobe level		
- Elevation	<-14 dB	<-15 dB
- Azimuth	<-12 dB	<-13 dB
Polarization isolation	<-25 dB	<-30 dB
Orbit exact repeat interval	<5 days	2 days
Orbit near repeat interval	16 days	16 days